

No-Lose Theorem for Discovering the New Physics of $(g-2)_\mu$ at Muon Colliders

American Physical Society

April Meeting

18/Apr/2021

Rodolfo Capdevilla

University of Toronto and
Perimeter Institute for Theoretical Physics



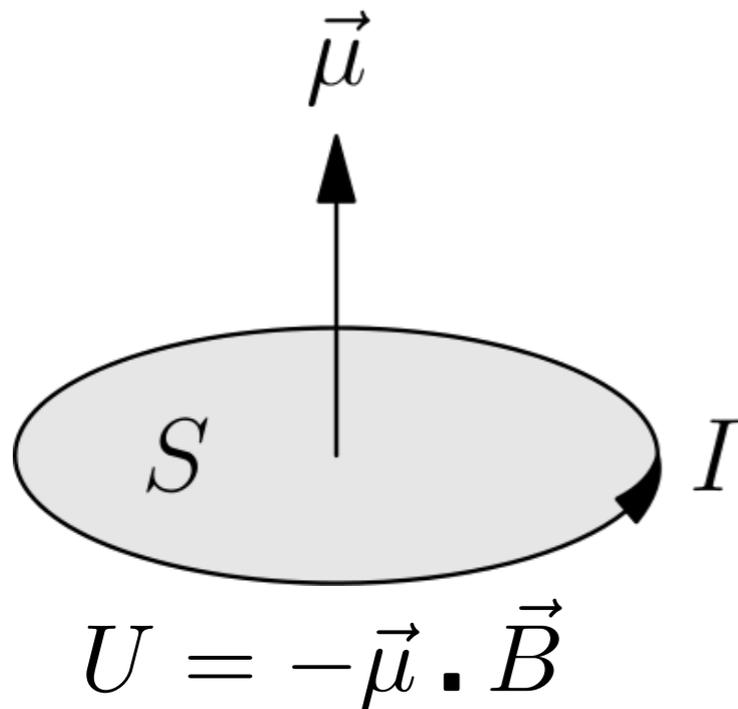
RC, David Curtin, Yonatan Kahn, Gordan Krnjaic, [arXiv:2006.16277](https://arxiv.org/abs/2006.16277), [arXiv:2101.10334](https://arxiv.org/abs/2101.10334)

Outline

1. Muon Anomalous Magnetic Moment
2. Implications for BSM Physics
 - Singlet Scenarios
 - Electroweak Scenarios
3. Summary

1. Muon Anomalous Magnetic Moment

- Magnetic moment (macroscopic)



- Possible to define for a fundamental particle

$$\vec{\mu} = -g \frac{\mu_B}{\hbar} \vec{S}$$

g-factor

- Relativistic quantum mechanics prediction

$$i\hbar \frac{\partial \phi}{\partial t} = \left[\frac{p^2}{2m} - \frac{\mu_B}{\hbar} (\vec{L} + 2\vec{S}) \cdot \vec{B} \right] \phi$$

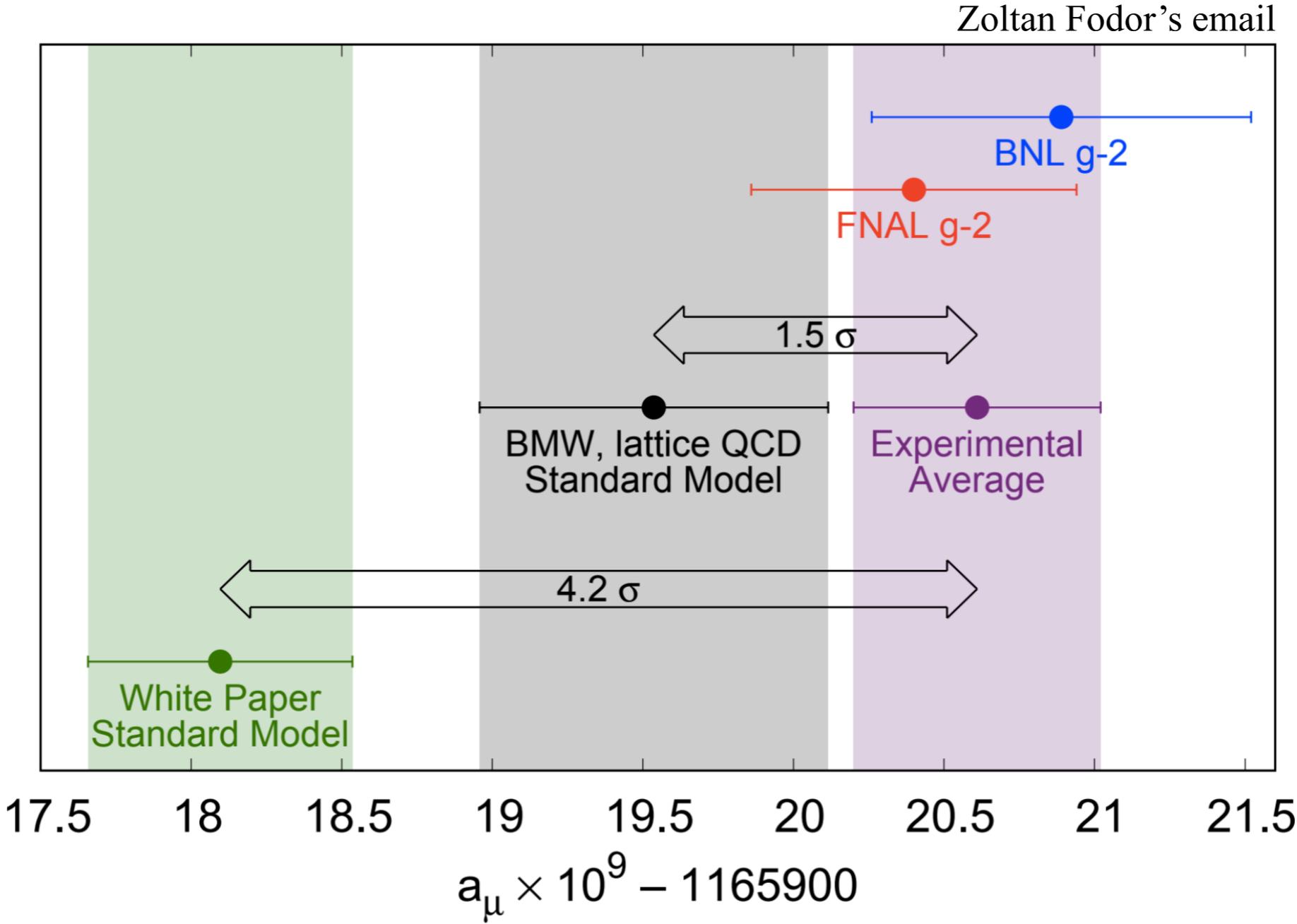
$g = 2$

- Anomalous Magnetic Moment

$$a = \frac{g - 2}{2}$$

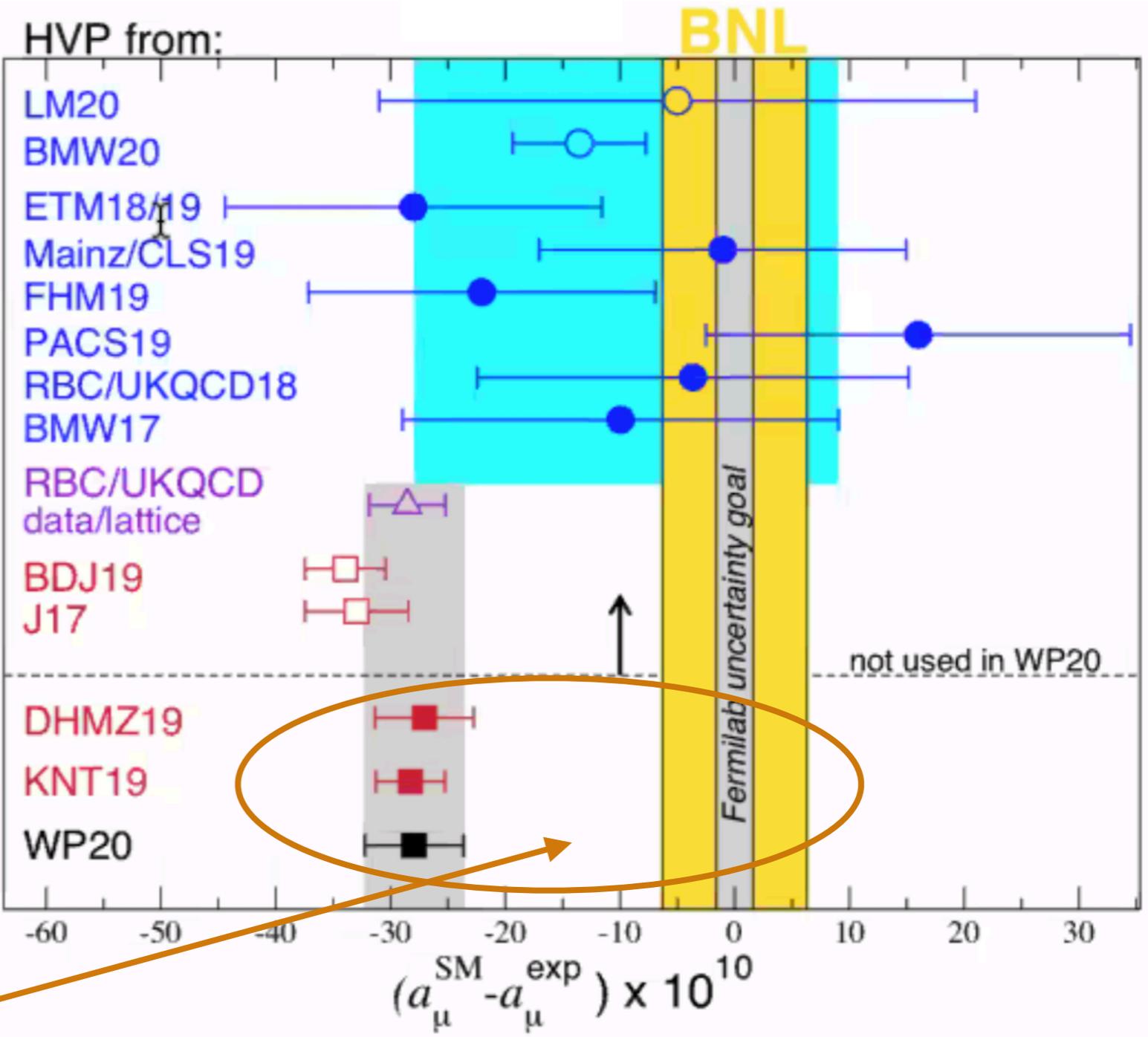
1. Muon Anomalous Magnetic Moment

- Theory vs Theory vs Experiments



1. Muon Anomalous Magnetic Moment

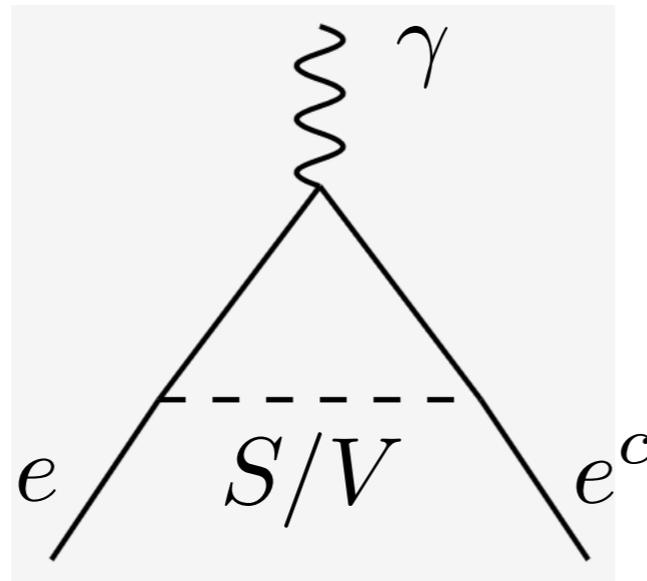
- Theory vs Experiment



What if goes up to 5 sigma?

2. Implications for BSM Physics

- A quick estimate



$$a_{\mu}^{\text{NP}} \sim \frac{g^2}{4\pi^2} \frac{m_{\mu}^2}{M_{\text{BSM}}^2}$$

- Electroweak-size couplings?

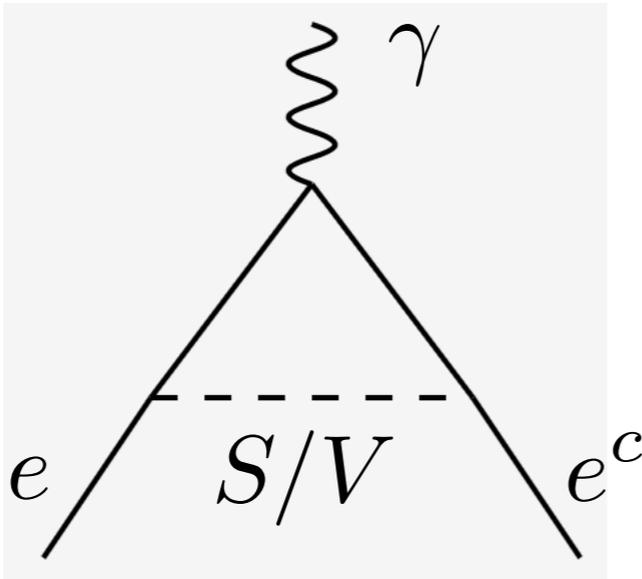
$$a_{\mu}^{\text{NP}} \sim \Delta a_{\mu} \sim 10^{-9}$$



$$g \sim 0.1$$
$$M_{\text{BSM}} \sim 100 \text{ GeV}$$

2. Implications for BSM Physics

- A quick estimate



$$a_{\mu}^{\text{NP}} \sim \frac{g^2}{4\pi^2} \frac{m_{\mu}^2}{M_{\text{BSM}}^2}$$

Weak coupling
Light mass

- Electroweak-size couplings?

$$a_{\mu}^{\text{NP}} \sim \Delta a_{\mu} \sim 10^{-9}$$

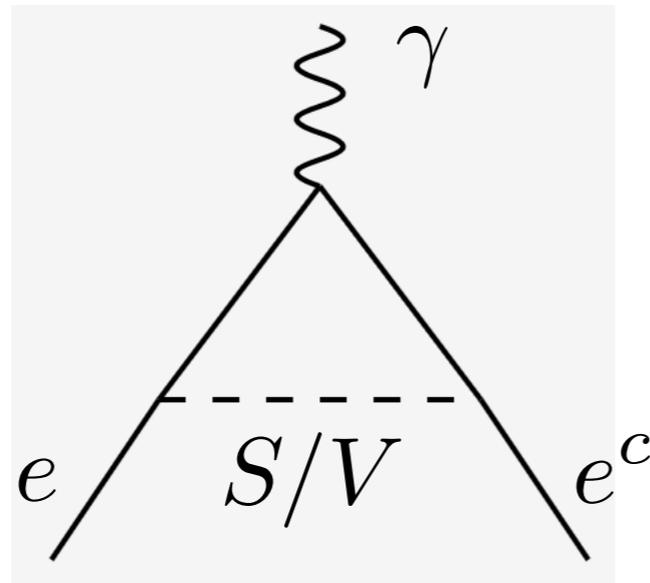


$$g < 10^{-2}$$

$$M_{\text{BSM}} < 1 \text{ GeV}$$

2. Implications for BSM Physics

- A quick estimate



$$a_{\mu}^{\text{NP}} \sim \frac{g^2}{4\pi^2} \frac{m_{\mu}^2}{M_{\text{BSM}}^2}$$

Strong coupling
Heavy mass

- Electroweak-size couplings?

$$a_{\mu}^{\text{NP}} \sim \Delta a_{\mu} \sim 10^{-9}$$

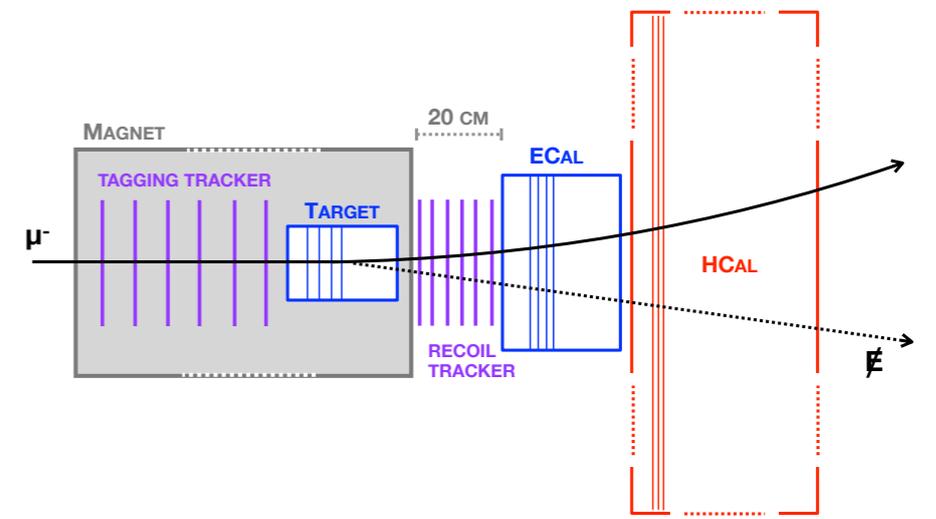
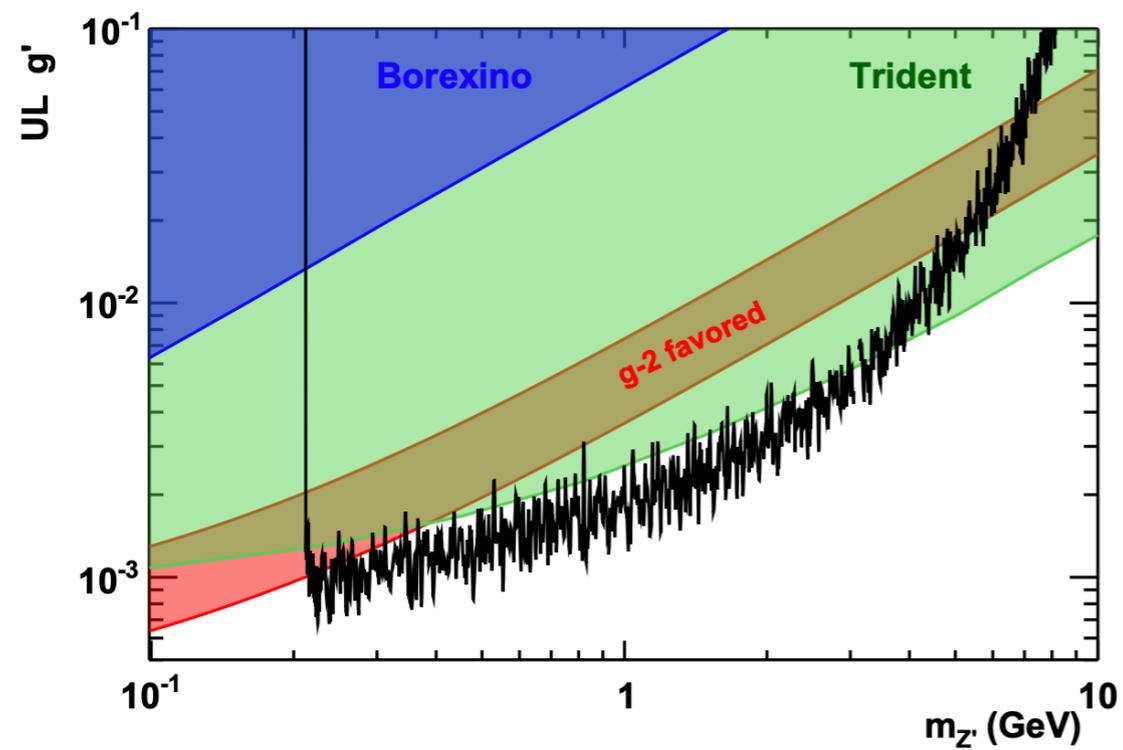
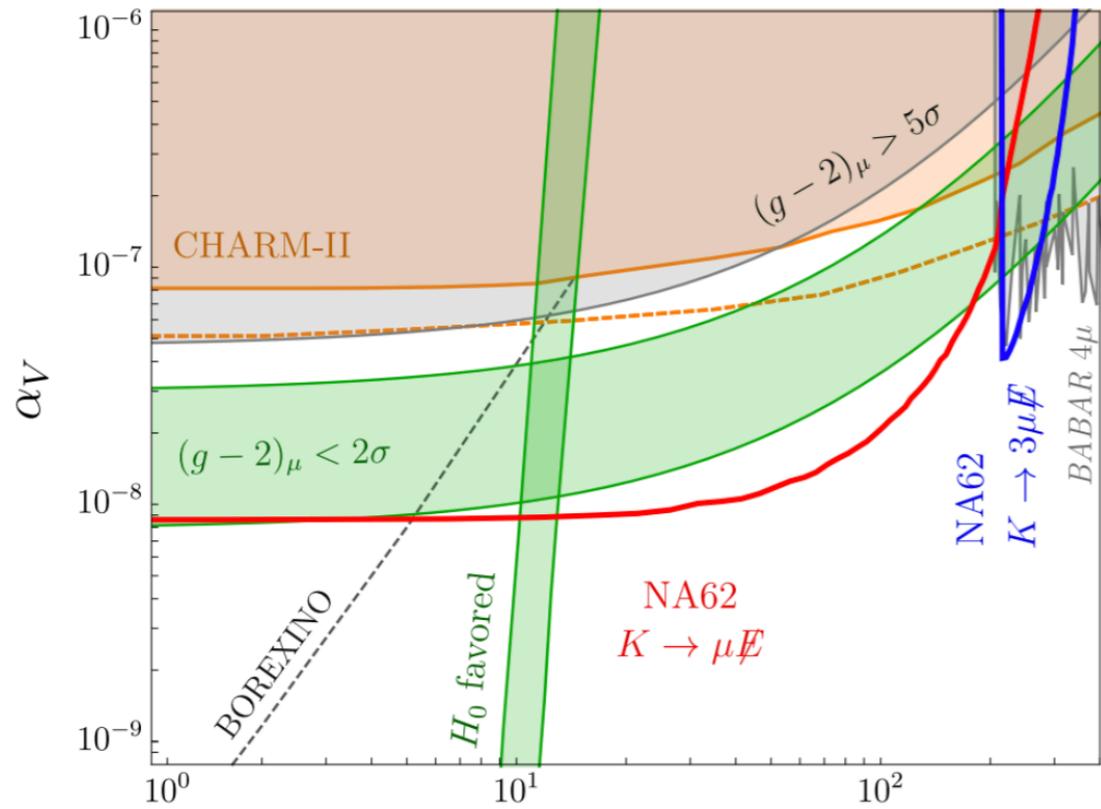


$$g \rightarrow \sqrt{4\pi}$$

$$M_{\text{BSM}} \rightarrow 10^? \text{ TeV}$$

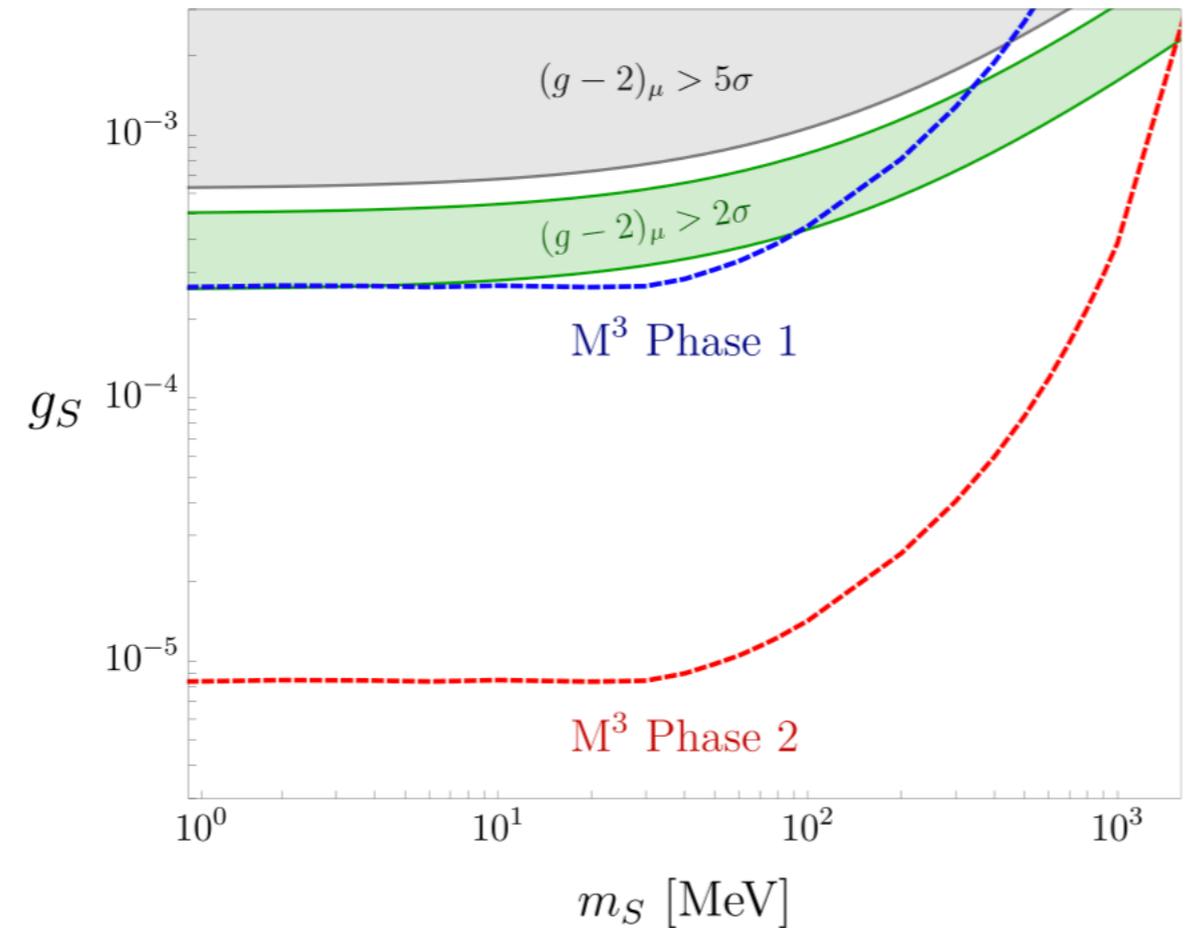
2. Implications for BSM Physics

- Light Weakly Coupled Sectors



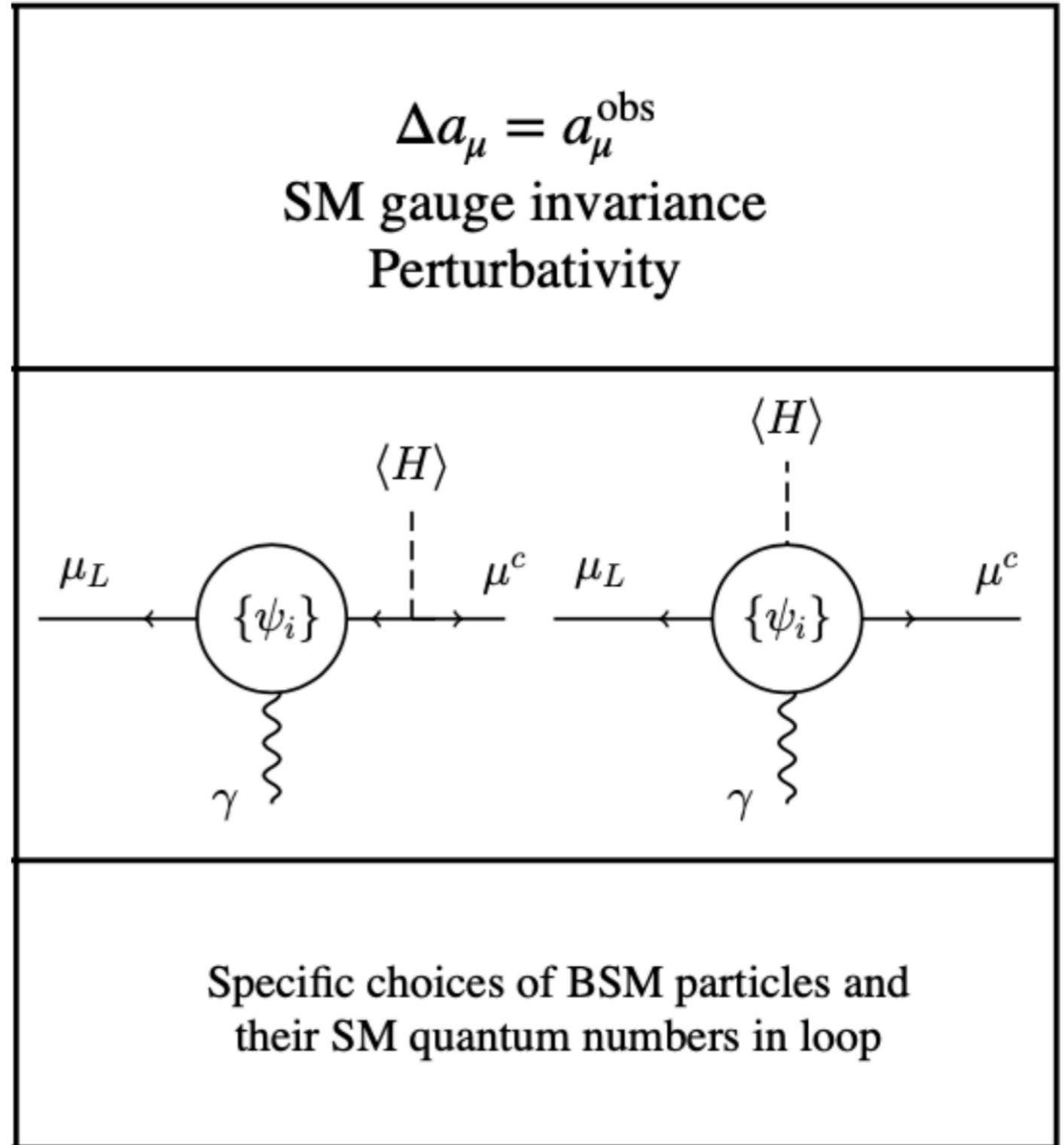
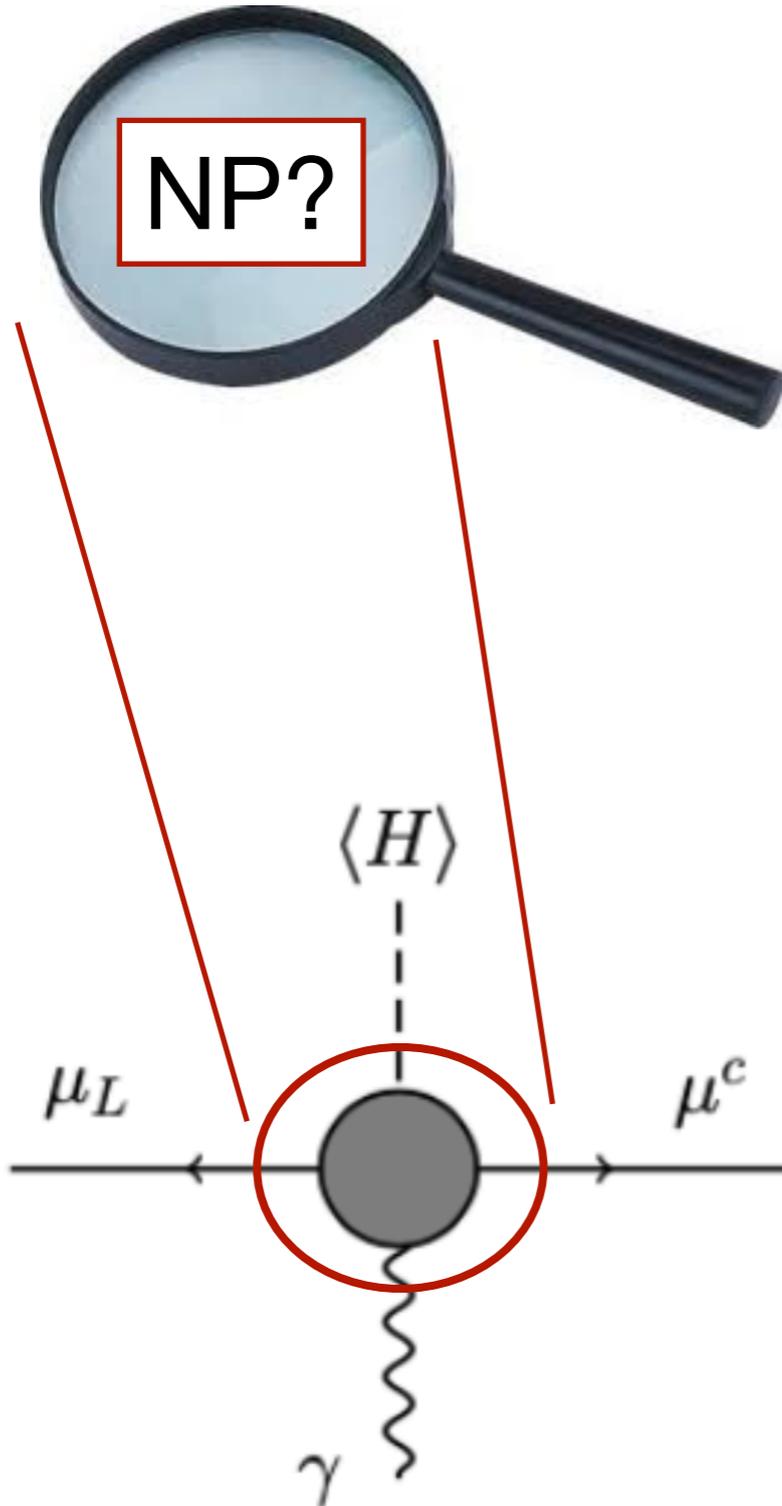
[YK, Krnjaic, Tran, Whitbeck, 1804.03144]

Invisibly Decaying Muon – Philic Scalar



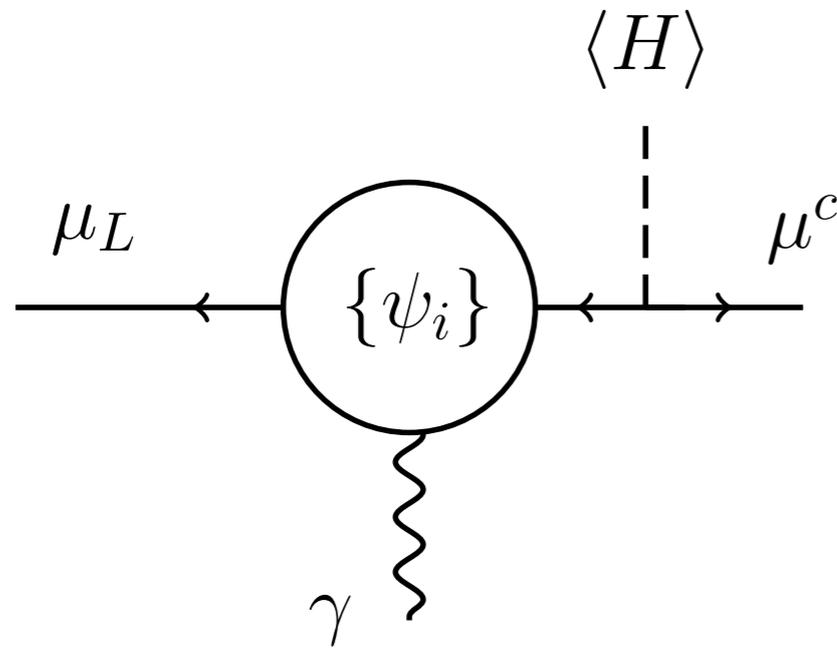
2. Implications for BSM Physics

- Is it possible to discover all BSM solutions to the $(g-2)_\mu$ anomaly?



2. Implications for BSM Physics

- Is it possible to discover all BSM solutions to the $(g-2)_\mu$ anomaly?

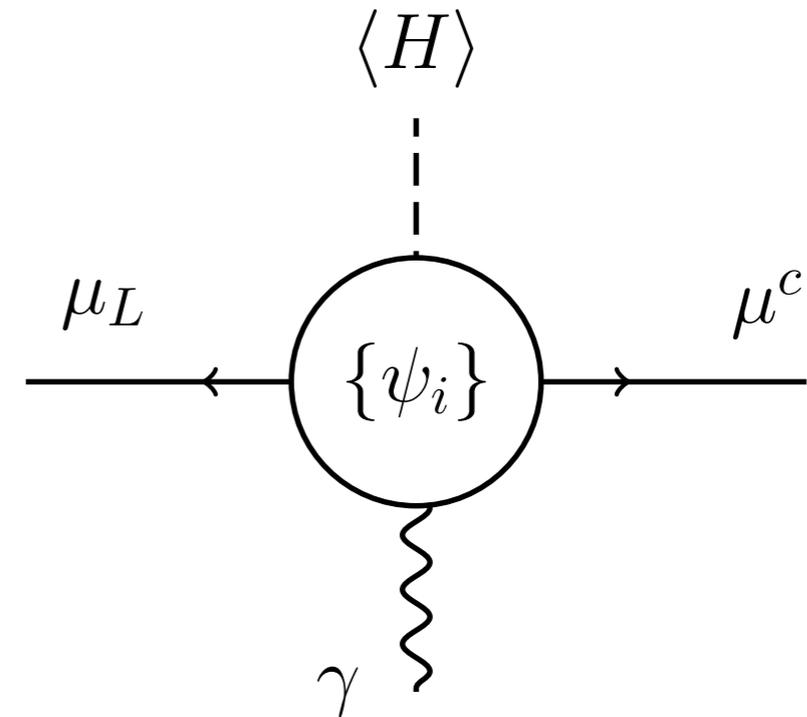


“Singlet scenarios”

(Introduce only SM singlets into the loop)

- Simple Models
- Phenomenology can be tricky

Produce singlets - Muon coupling



“Electroweak scenarios”

(Introduce at least one new charged state)

- Complicated Models
- Easy Phenomenology

Focus lightest charged state!

- Is it possible to discover all BSM solutions to the $(g-2)_\mu$ anomaly?

Particularly relevant for a Muon Collider:

- For singlet scenarios, can couple to singlet via same coupling that makes $g-2$
- For EW scenarios, can reach high energies and discover "all" charged particles with masses $< E_{cm}/2$

“Singlet scenarios”

(Introduce only SM singlets into the loop)

- Simple Models
- Phenomenology can be tricky

Produce singlets - Muon coupling

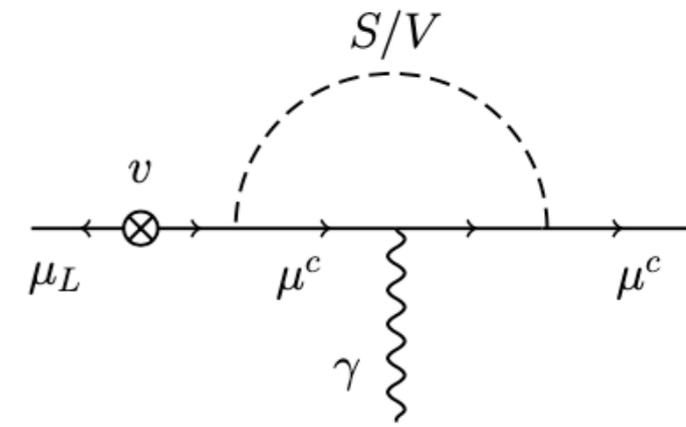
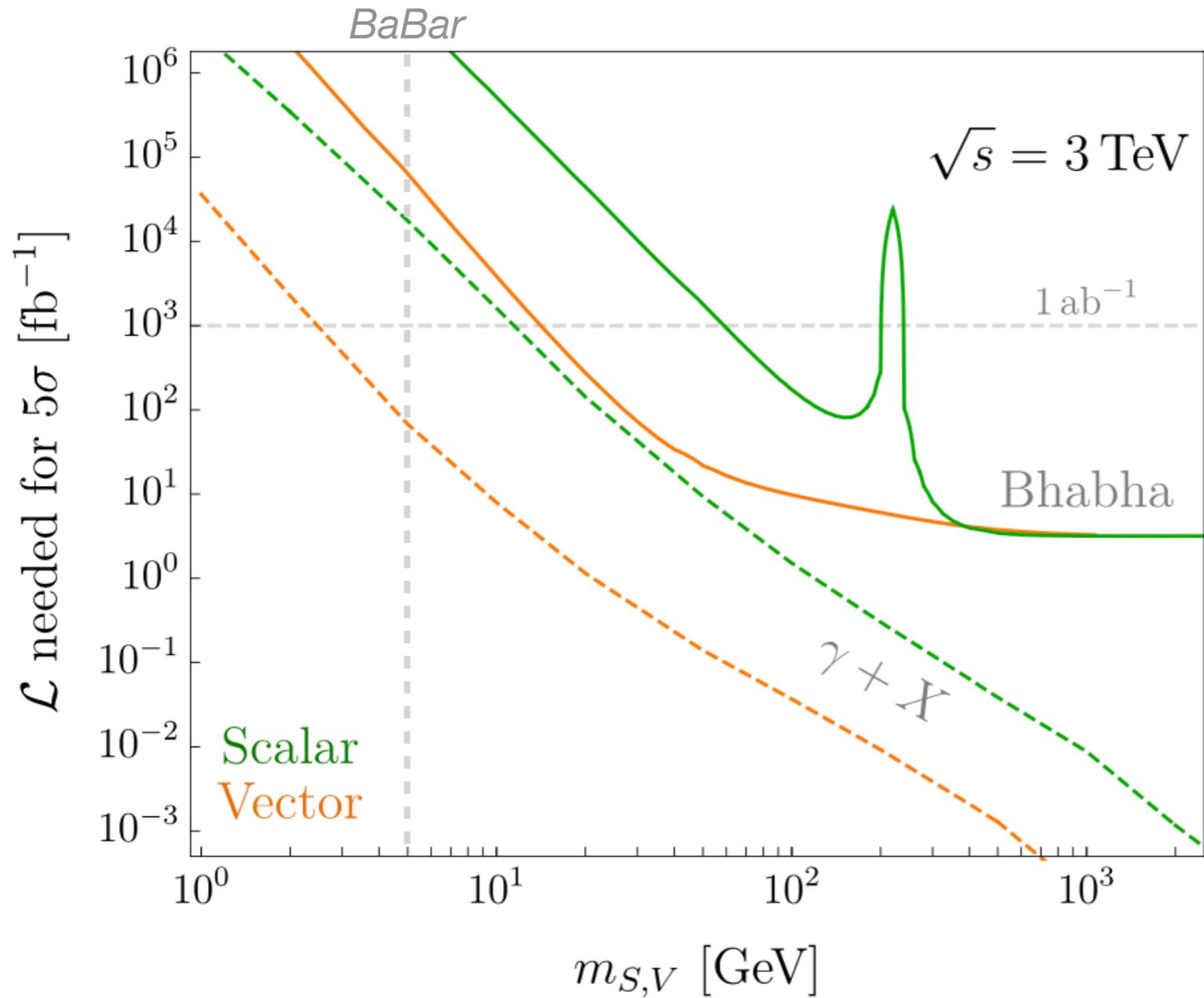
“Electroweak scenarios”

(Introduce at least one new charged state)

- Complicated Models
- Easy Phenomenology

Focus lightest charged state!

2. Implications for BSM Physics: Singlet Scenarios



“Singlet scenarios”

A 3 TeV Muon Collider can probe all Singlet explanations for $g-2$



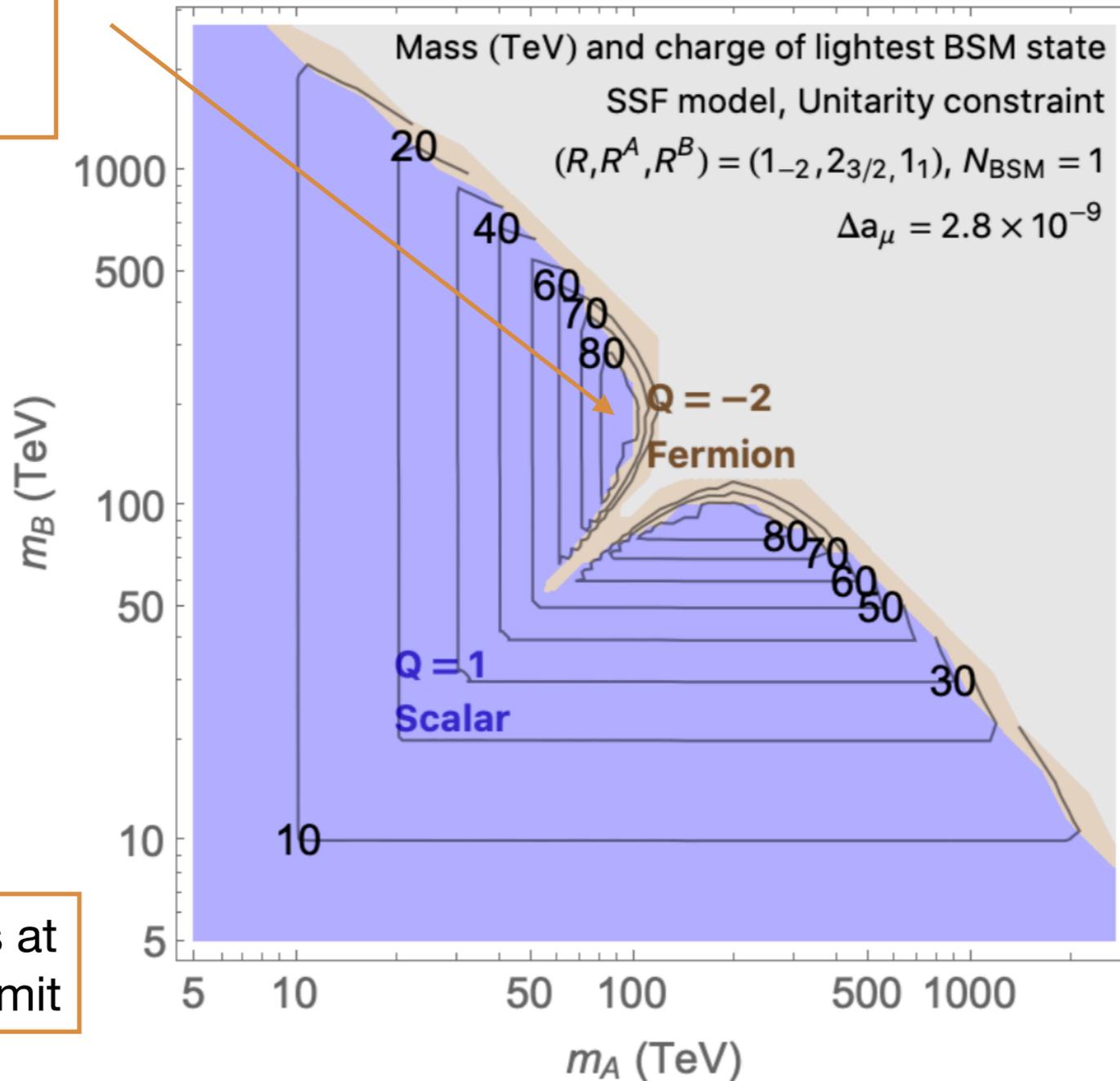
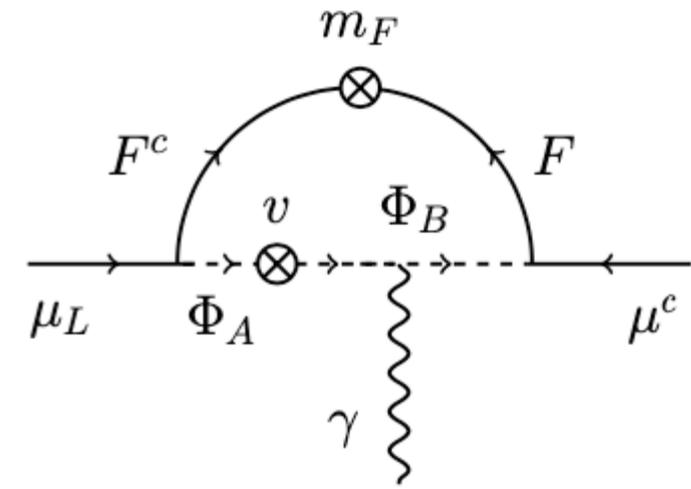
2. Implications for BSM Physics: EW Scenarios

If only perturbative unitarity

Heaviest states at ~ 100 TeV

“Electroweak scenarios”

Unitarity only

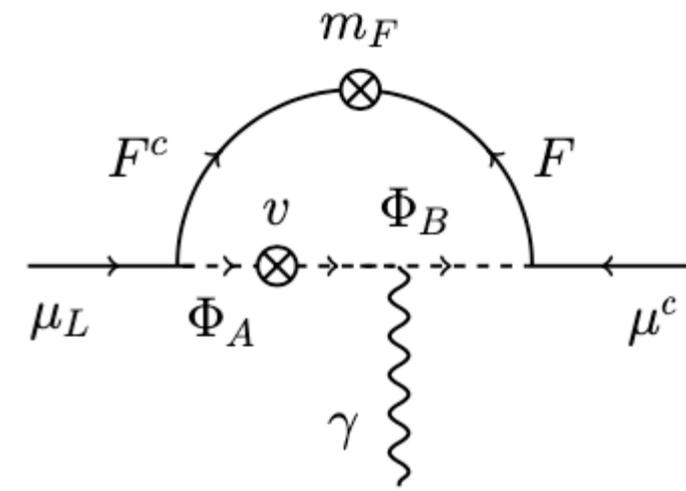
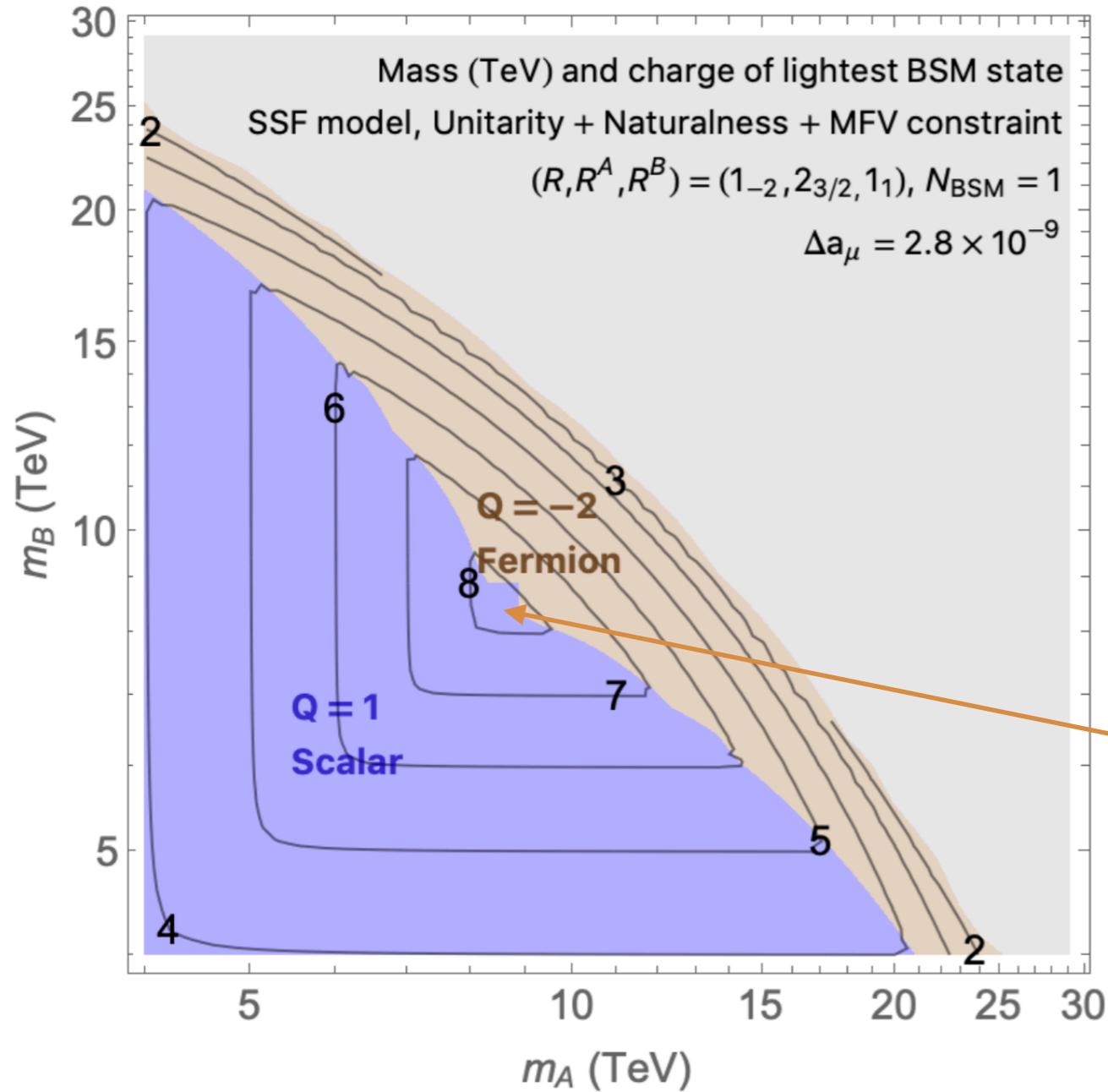


- EW representations up to **3**
- Models with charged scalars up to $Q = 2$
- BSM number of flavours up to 10

N_{BSM}

Maximal couplings at the perturbativity limit

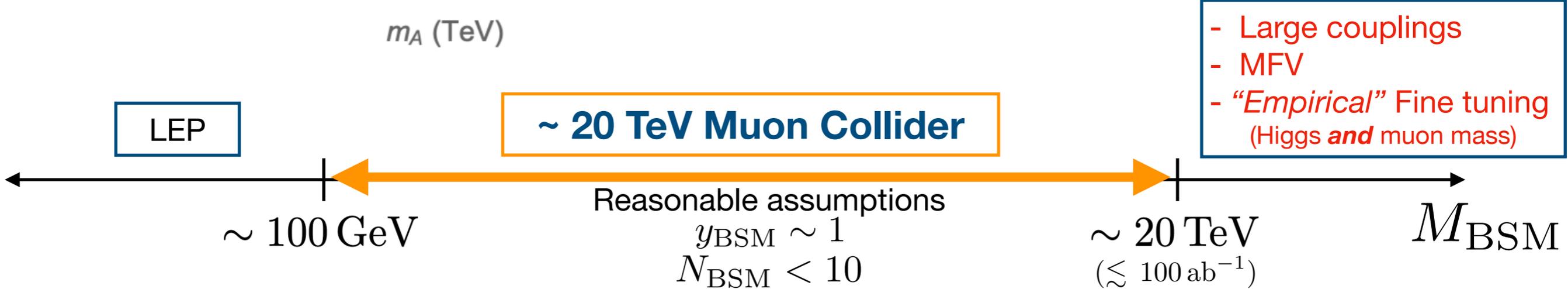
2. Implications for BSM Physics: EW Scenarios



Unitarity
 Naturalness
 MFV

Heaviest states at
 $\sim 10 \text{ TeV}$

- Large couplings
- MFV
- "Empirical" Fine tuning (Higgs *and* muon mass)



Summary

1. Measurements of the anomalous magnetic moment of fundamental particles are important laboratories for high precision tests of the SM
2. The lack of evidence of the new physics responsible for $(g-2)_\mu$ in other experiments might indicate that such new physics is so heavy that it cannot (yet) be produced. For the most perverse BSM scenarios $M \sim 100$ TeV
3. Reasonable assumptions about flavour and fine tuning suggest that the most perverse scenarios that can explain $(g-2)_\mu$ might actually point at a mass scale of about 10 TeV
4. A MuC is in a privileged position: It collides the particles of the anomaly and it can reach high COM energies. It is possible to establish a No-Lose theorem for a MuC program in case $g-2$ is confirmed as a source of new physics!

Thanks!